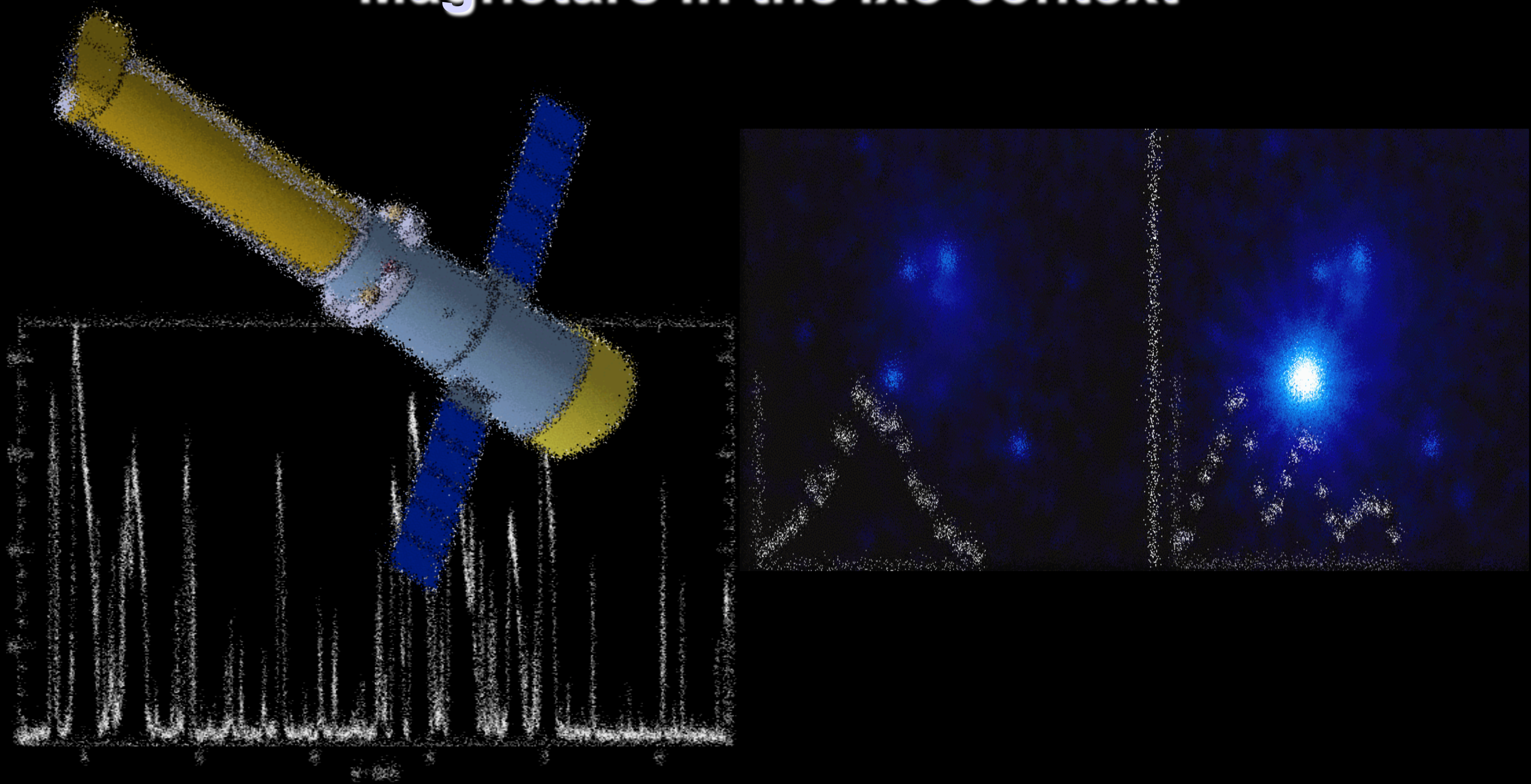
Magnetars in the ixo context



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...and many inputs from: D. Gotz, S. Zane, L. Stella, R. Turolla, P. Esposito, A. Watts, M. Feroci, F. Muleri, S. Mereghetti

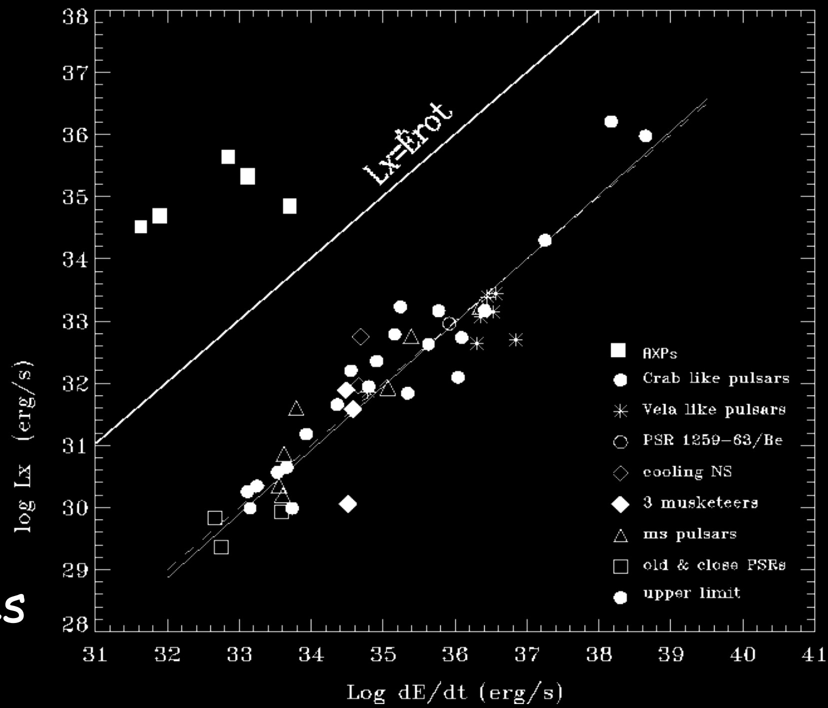
Paris, 28th Apr 2010

Why Magnetars ?

Loss of rotational energy is orders of magnitudes too small (10^{30}erg/s) with respect to the observed persistent Lx

No accretion from a companion (M>Mjup)

No Doppler modulation/shift in the spin pulses



In analogy with isolated rotation-powered NS

$$P\dot{P} = \left(\frac{8\pi^2 R_{ns}{}^6}{3c^3 I}\right) B_0{}^2 \sin^2\alpha$$

$10^{14\text{-}15}$ Gauss → MAGNEtic sTARS

Definition:

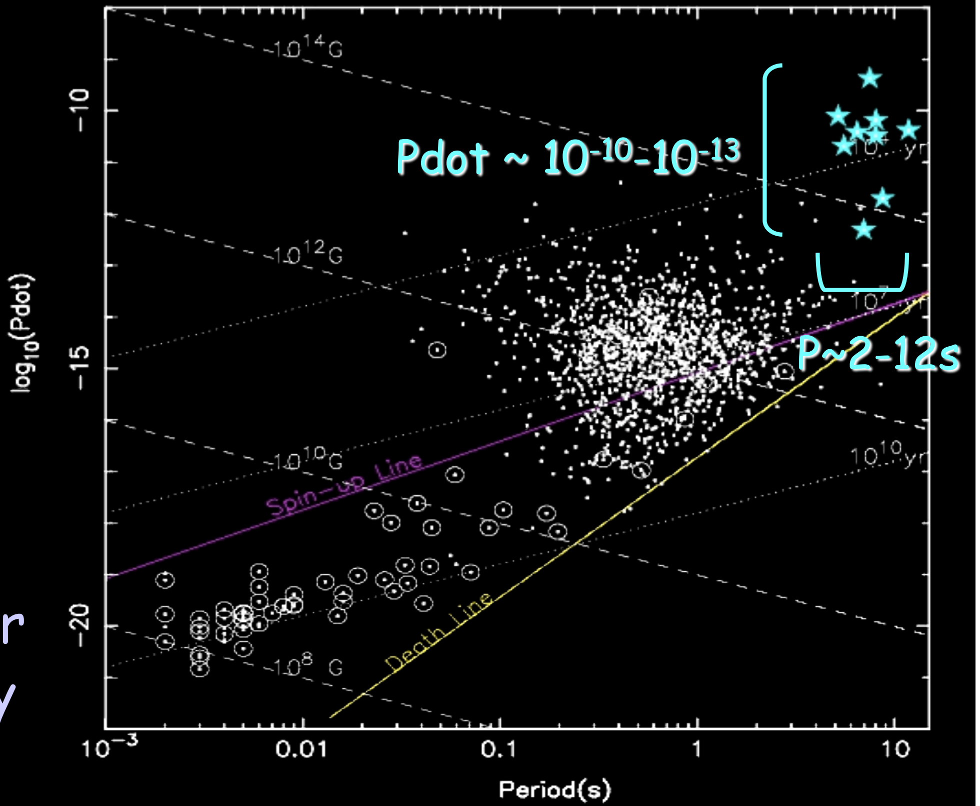
(Isolated) neutron stars where the main source of energy is the magnetic field [most observed NS have B = 10^9 - 10^{12} G and are powered by accretion, rotational energy, or residual internal heat].

Several indirect evidences (for high B) collected through years !

Two (?) classes of Magnetars (historically)

Soft Gamma-ray Repeaters

- Discovered in 1979 as sources of hard X-ray bursts and giant flares
- 6 confirmed SGRs



Anomalous X-ray Pulsars

- Identified in the 90's as a peculiar class of soft and persistent X-ray pulsar with no signs of binary companions
- 9 confirmed AXPs

- Spin periods: 2 - 12 s
- Period derivatives: 10^{-10}-10^{-13} ss^{-1}
- Short (~100ms) X/γ bursts / Glitches
- Rare Giant Flares (>10^{47} ergs; minutes)
- Associated with SNRs (4) and massive open clusters (3) with M turn-off of 30-40Msolar and b<0.5 → ~10^4-10^5 yr

(See review: Mereghetti 2008, A&A Rev. 15, 225)

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1) BURSts/FLARES

Local and/or global MF re-configuration

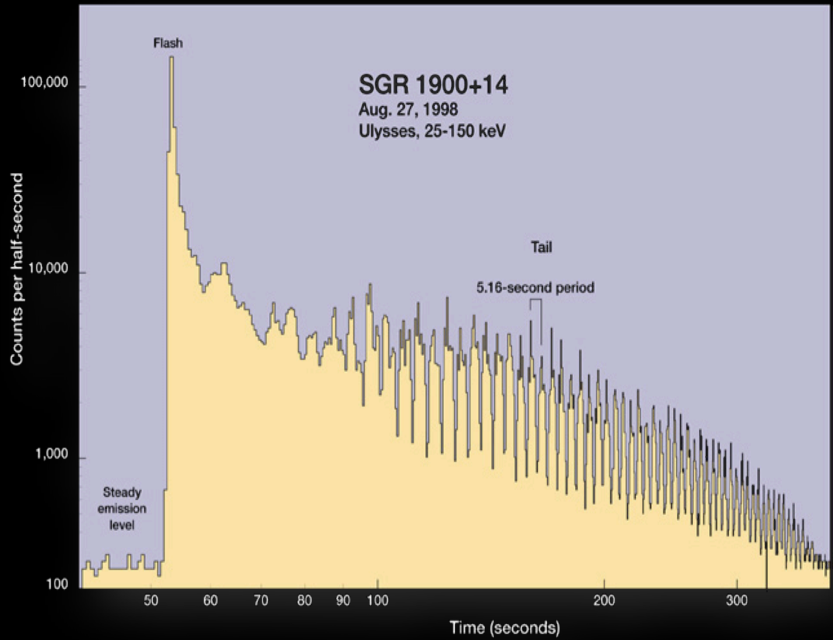
Sometimes observed together with glitches and outbursts

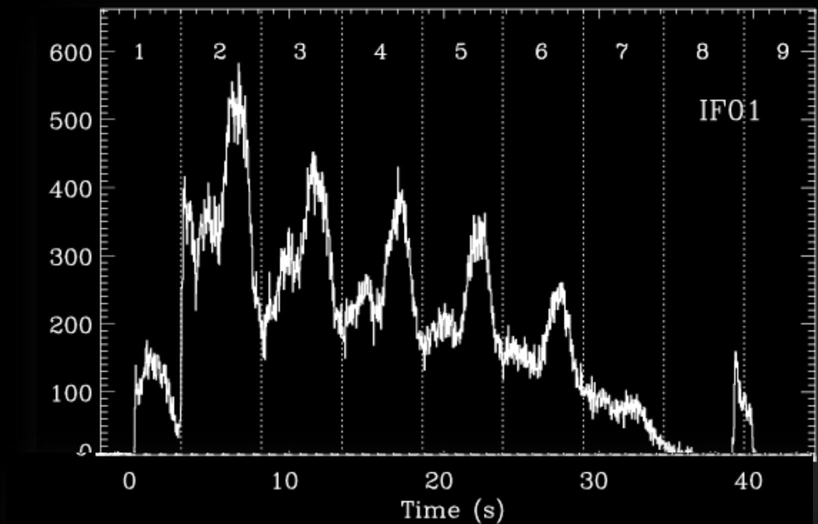
Giant flares: 3 from 3 different SGRs in 30years

Fluence: from 10^{44} up to 10^{47} ergs

Duration: 5-10 minutes

Ringing Tail: up to 10^{44} ergs and pulsed





Intermediate flares: tens in SGRs (a few in AXPs)

Fluence: ~ 10^{42} up to 10^{44} ergs

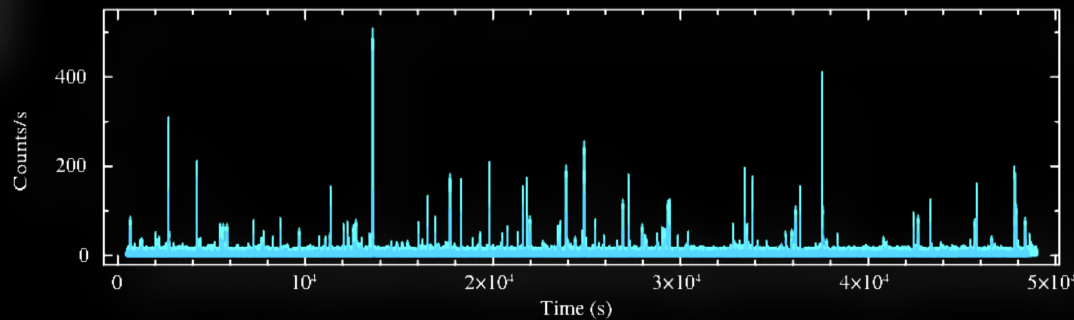
Duration: 0.5-40 seconds

Ringing tail: sometimes

Bursts: thousands from SGRs/AXPs

Fluence: 10^{38} up to 10^{42} ergs

Duration: 10-500ms

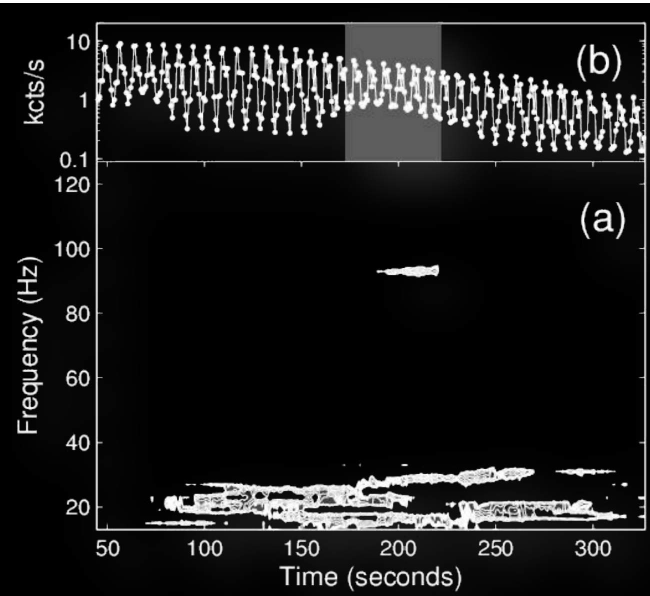


A lot of photons but difficult to observe

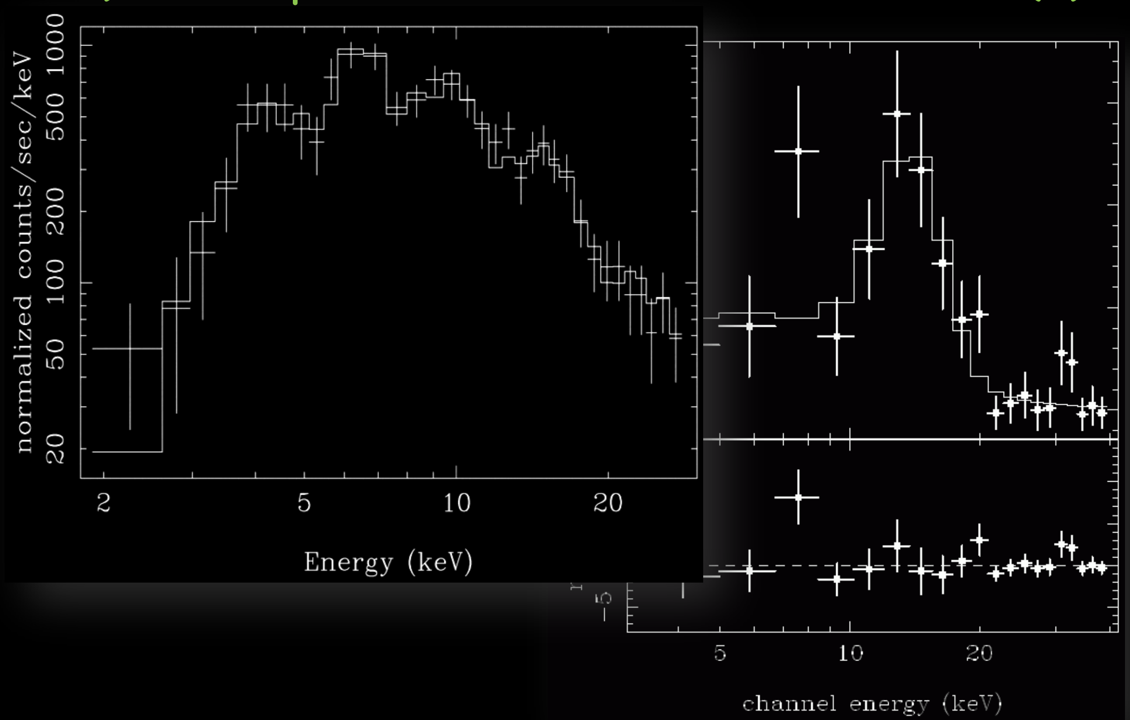
BURSts/FLARES

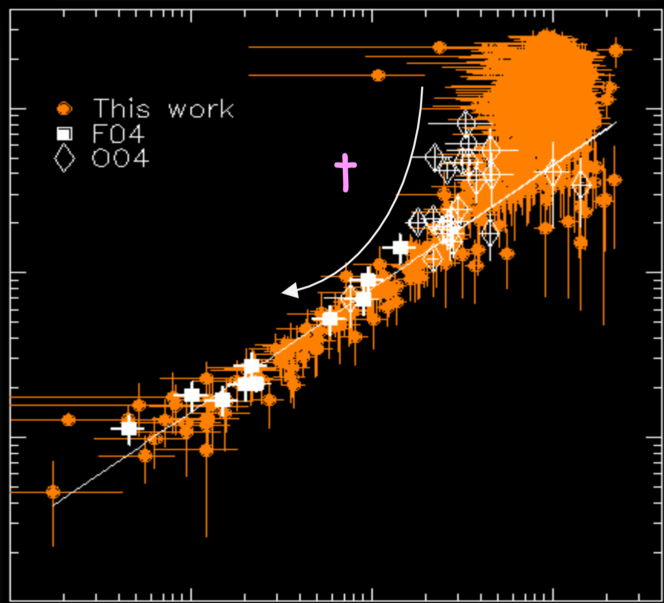
Phenomenology in the context of IXO

1) QPOs in GFs/IFs → NS EOSs



2) Absorption/emission features → MF (?)

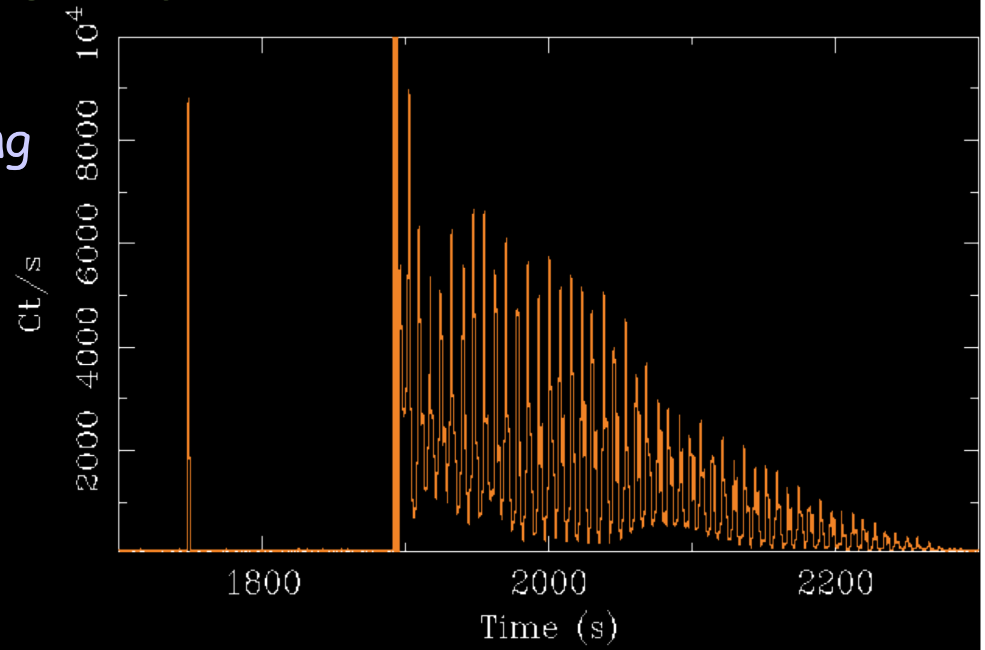


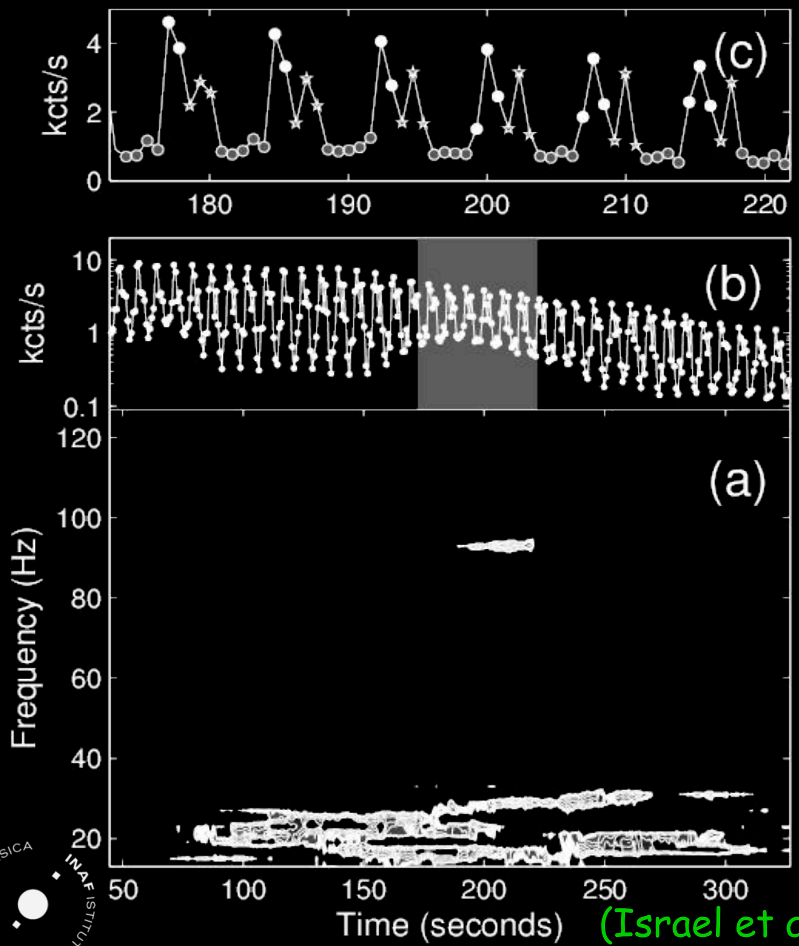


3) O- and E-mode pol. photons → Magnetically confined fireball and polarization

SGR1806-20: QPOs in the GF tail

27th December 2004 hyperflare
Up to 10^{46}-10^{47} ergs released during the first ~ 0.6s (@ a distance of 8-15kpc),
1 erg /cm^2 at Earth !!





(Israel et al. 2005)

Similar phenomenology and frequencies also during The 1998 GF from SGR1900+14

18–30, 61, 92.5, 150 Hz
28.5, 52.5, 84, 155.5 Hz.

Easily accounted for TOROIDAL GSOs (ℓ=2,4,7,13)

Direct way to have info from the NS surface

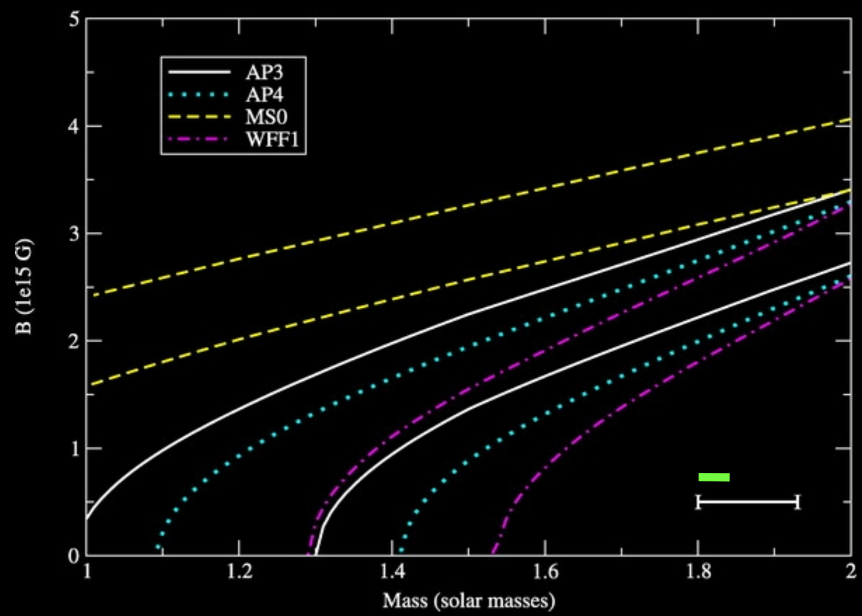
QPOs as seismic oscillations

Period of the fundamental (l=2, n=0) for a non-rotating, non-magnetic star:

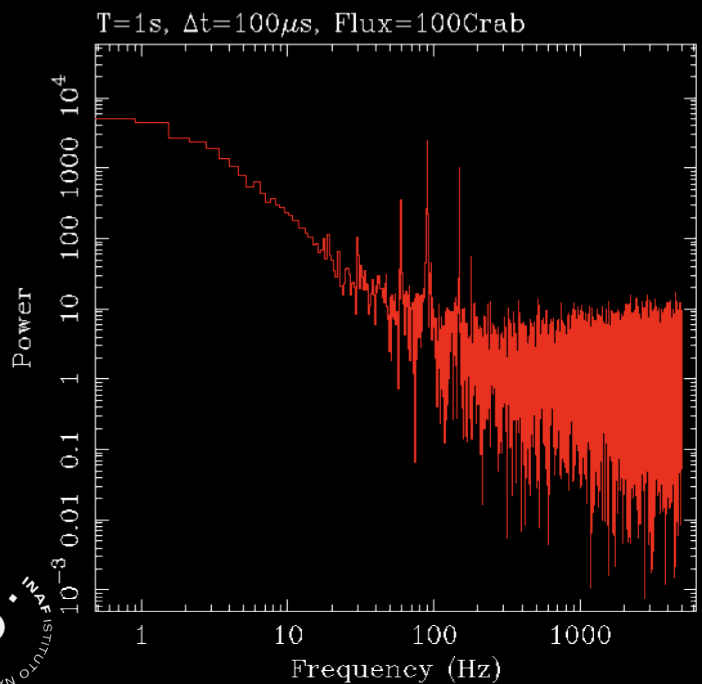
$$P_{({}_2t^0)} = 33.6 R_{10} \frac{0.87 + 0.13 M_{1.4} R_{10}^{-2}}{(1.71 - 0.71 M_{1.4} R_{10}^{-1})^{1/2}} ms$$

Considering also the magnetic fields,

$$P_{({}_l t^0)} = P_{({}_2 t^0)} \left(\frac{6}{l(l+1)} \right)^{1/2} \left[1 + \left(\frac{B}{B_\mu} \right)^2 \right]^{-1/2}$$



(Lattimer & Prakash 2001; Duncan 1998; Strohmayer & Watts 2005; Watts & Strormayer 2006)



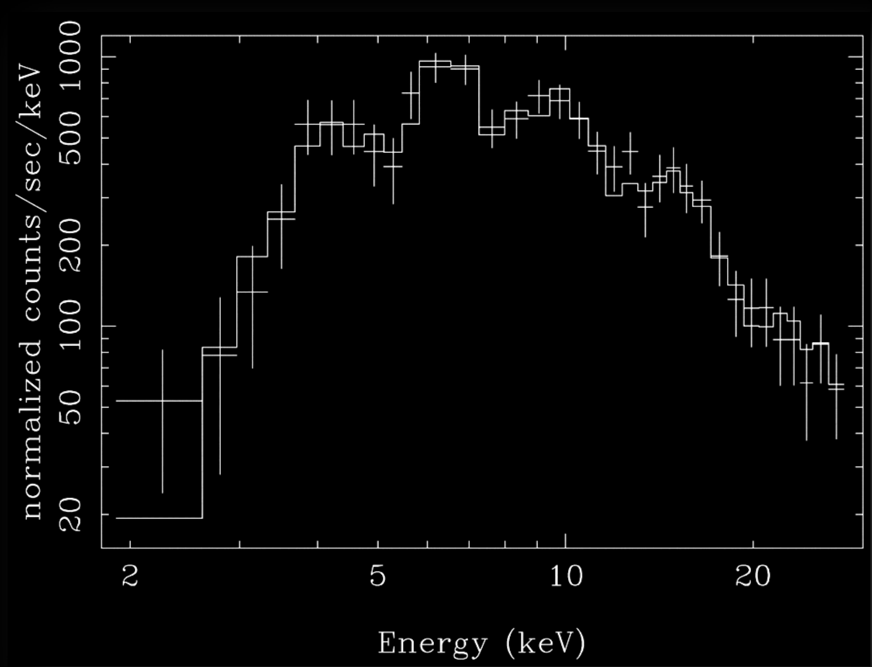
HTRS simulation of a 10Crab burst/IF (~1s long)

we simulated QPOs at l=2,4,7,13,16), rms of less than 5%

Theory predicts that QPOs should be seen in Burst/IF too, but not observed so far (not enough statistics)

If detected the unc on Mass can be drastically reduced [HTRS]

Absorptions in SGR bursts (SGR1806-20)



Eabs not equally spaced

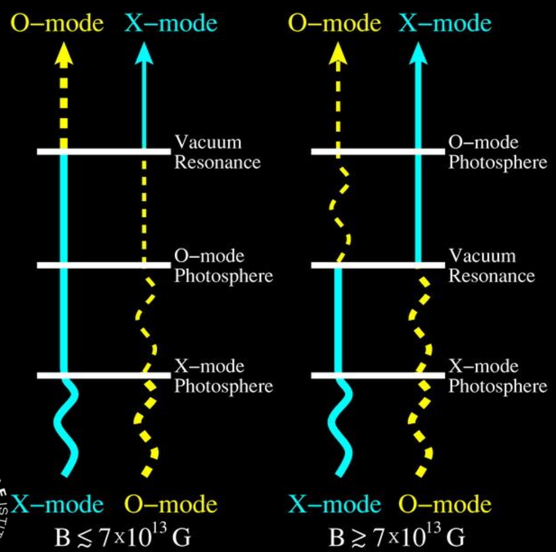
TABLE 2

BEST-FIT PARAMETERS FOR THE LINE FEATURES

Line Feature	Energy (keV)	Width (keV)	Depth
1	5.0 ± 0.2	0.24 ± 0.1	1.9 ± 0.6
2	7.5 ± 0.3	0.45 ± 0.2	1.2 ± 0.4
3	11.2 ± 0.4	1.2 ± 0.5	0.9 ± 0.3
4	17.5 ± 0.5	1.1 ± 0.7	1.0 ± 0.4

NOTE.—The cyclotron absorption model is described in Mihara et al. 1990.

(Ibrahim et al. 2002,2003)

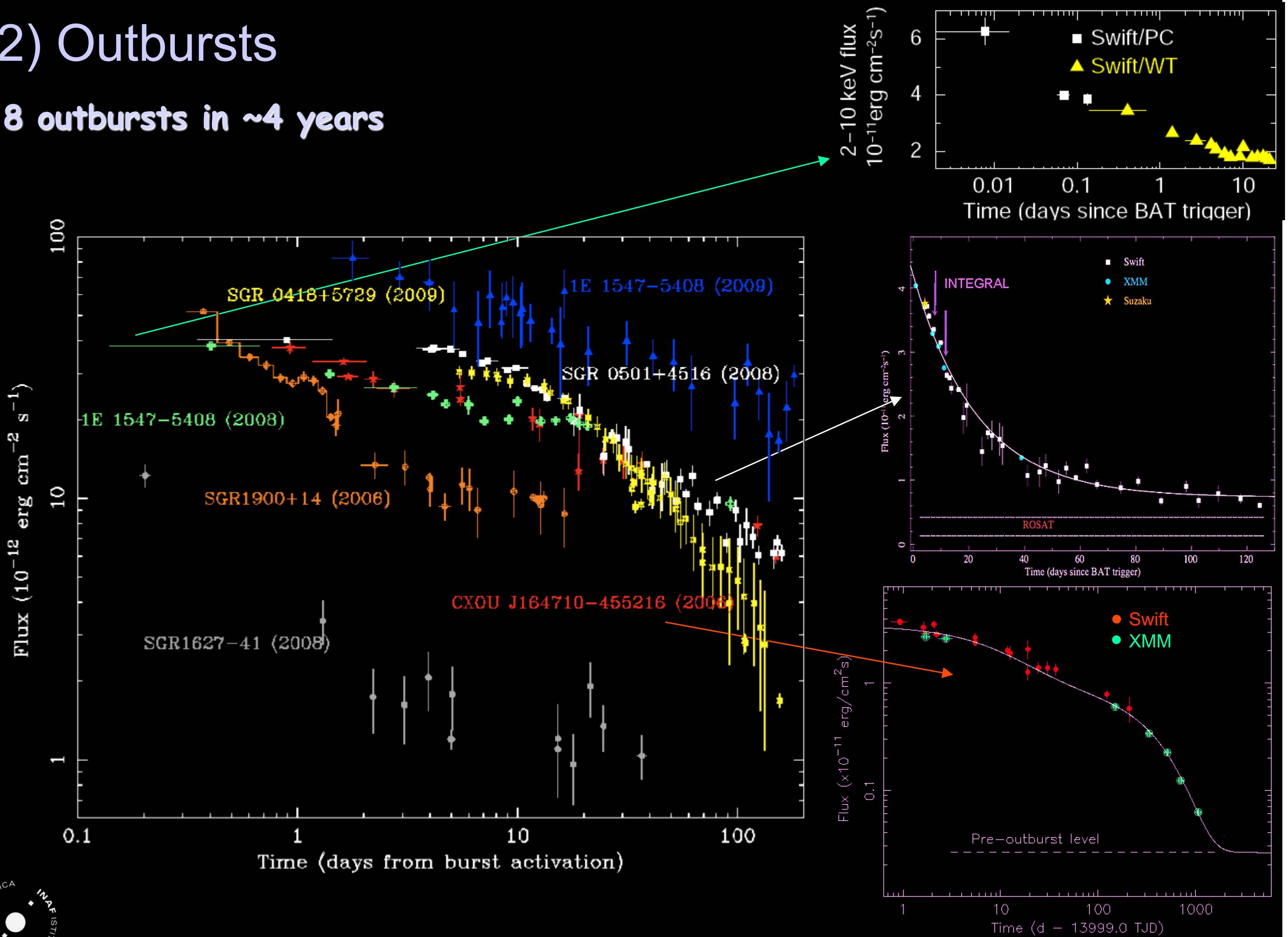


Vacuum polarization is expected to suppress the p-CAFs and softening the high-energy tail of the spectrum for B > B_{crit} (numerical calulation only for the thermal component and for emission form the NS atmosphere).

NOT clear if applicable to a trapped fireball too.

2) Outbursts

8 outbursts in ~4 years

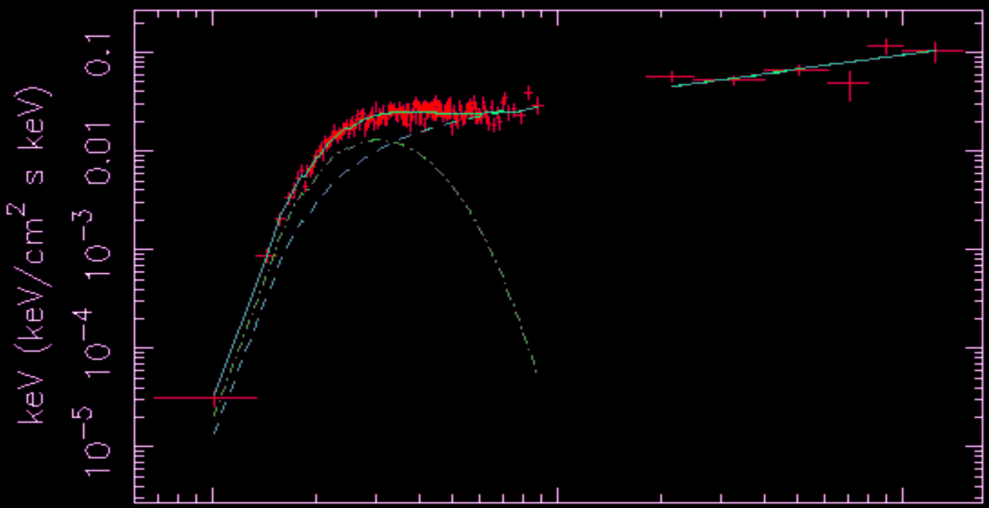


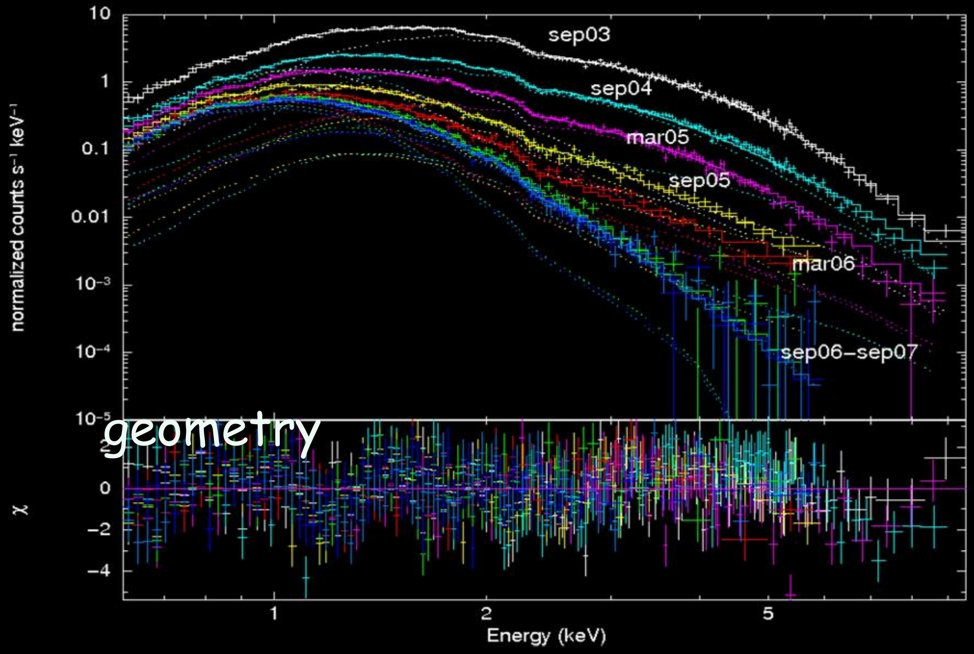
Paris, 28th Apr 2010

Outbursts

Phenomenology in the context of IXO

1) variable hard tail and its link with softer components → photons propagation in high MFs

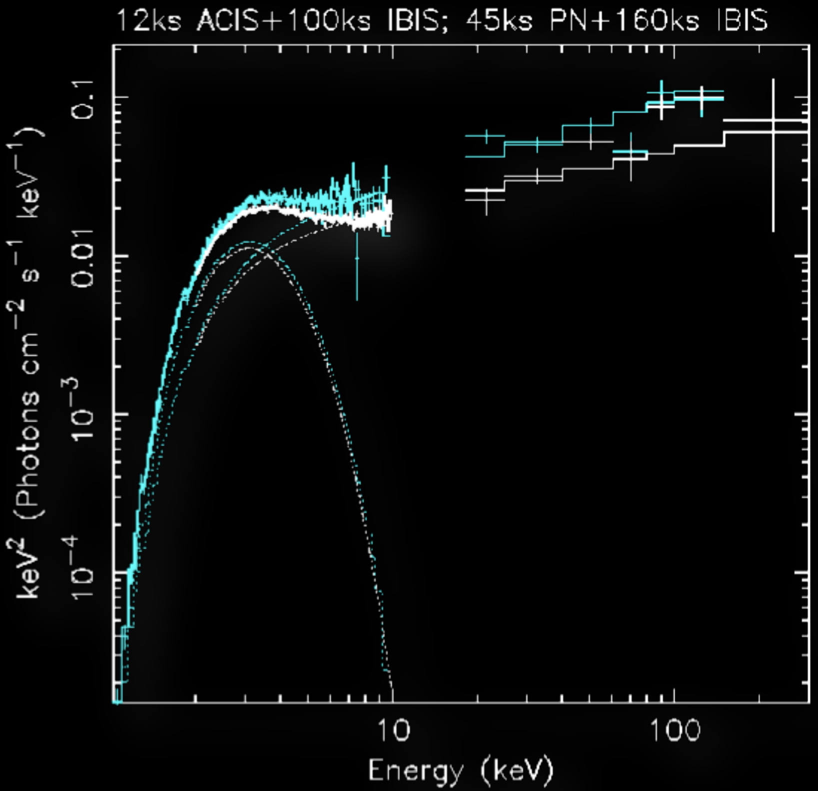


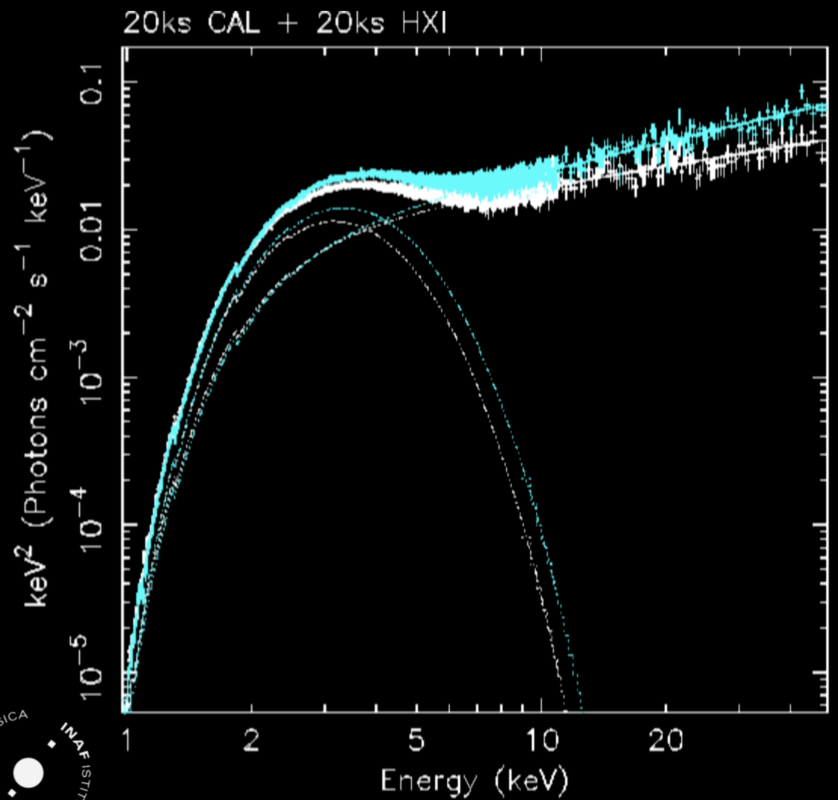


3) Monitoring of the outburst/flux decay as a function of timing parameters → emission geometry

broad band spectra

First evidence of variations in the hard tail on timescales of days. Γ evolves from 1.55 to 1.35 (but unc. are ~0.15). Note the Texp !!!





Simulated contiguous obs: Unc. on Γ of the order of 0.03
Shorter timescales… better sampling of variations
Spectral turn in between 10-20keV → HXT

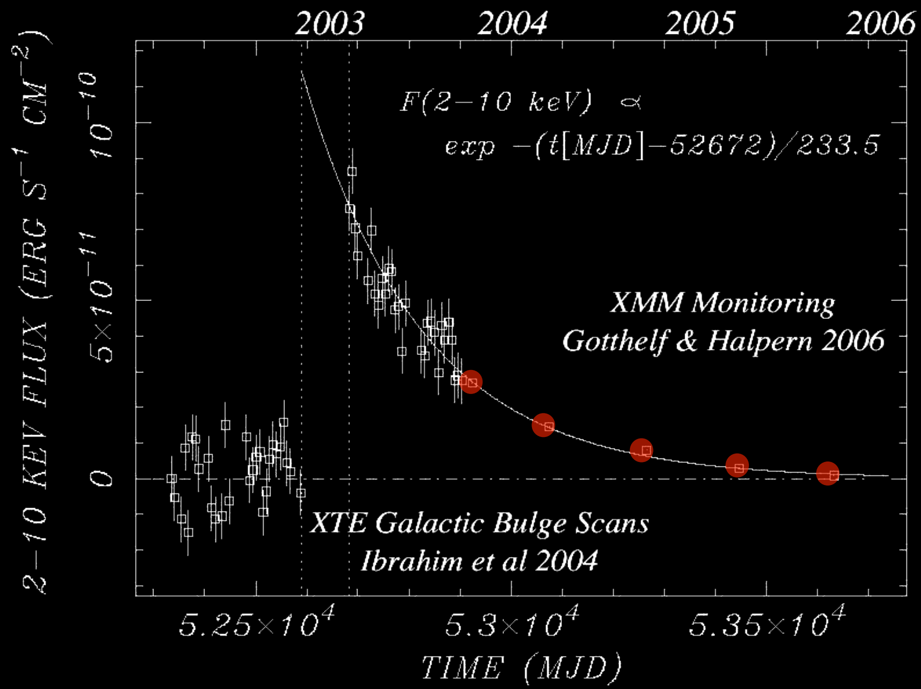
Soft/Hard correlation: upscattering in the magnetosphere (current models)

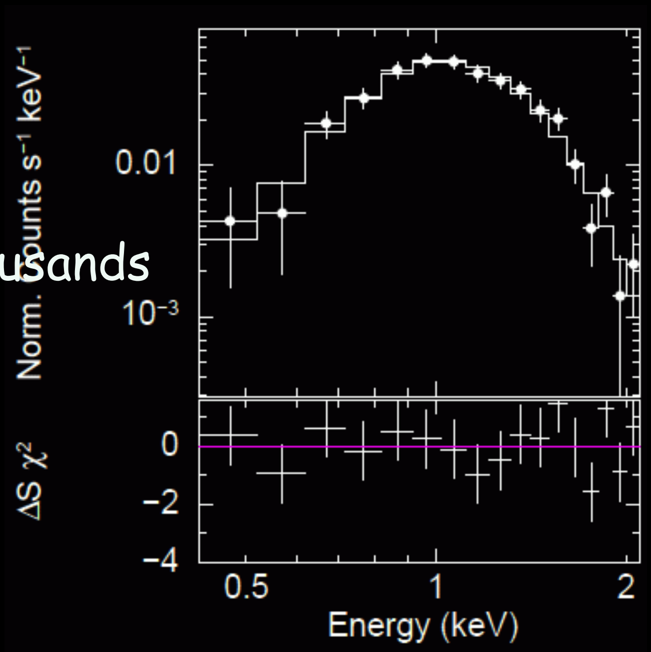
3) Quiescence

Phenomenology in the context of IXO

1a) Persistent magnetars (less than 10 objects) have Lx ~ 10^{35}-10^{36} erg/s [4%<PF<80%]

1b) Transient magnetars are faint in quiescence, Lx ~ 10^{31}-10^{33} erg/s [PF<15-20%; 1 case 80%]





2) Characterized by an almost thermal spectrum similar to that of thousands ROSAT sources

NEW objects identified mainly through their outbursts.

The identification of new magnetars is expected to impact on the NS demography.

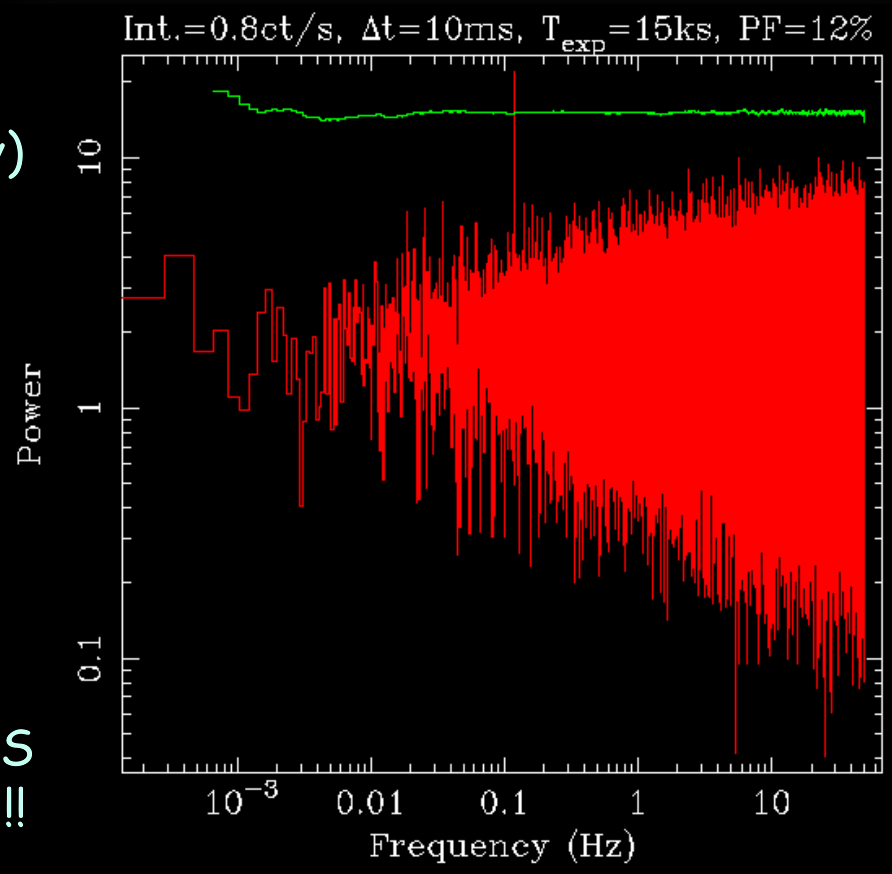
Quiescence

Can we identify more magnetars in our Galaxy by studying them in quiescence ?
And what about magnetars in other Galaxies (M31, MCs) ?

HTRS simulation for a source of 0.8ct/s corresponding to:

- Lx~10^{32} erg/s (quiescence in Milky Way)
- Lx~10^{36} erg/s (persistent obj. in M31)
- Lx~10^{34} erg/s (persistent obj. in MCs)

ONLY 15ks to reach a sensitivity level of ~10% in PF



Why important ?

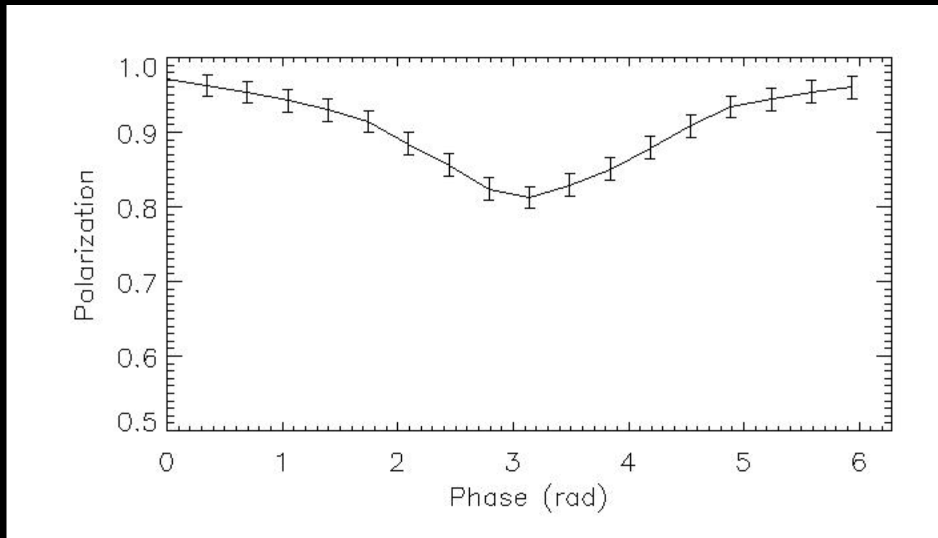
Currently models predict a number of magnetars up to 10%-20% of the total NS population… still many to be discovered !!

Polarimetry and persistent magnetars

High degree of polarization expected (true for all magnetar manifestations) e.g. Lai et al. (2010) in "X-ray Polarimetry: A New Window in Astrophysic"

Simulation of 100ks observation of 4U 0142+61 (4 mCrab), E>4 keV
Light curve divided in 18 phase bin.
In each:
- Unc. on polarization, 1.5 %
- Unc. on phase angle 0.7 degrees

[Similar results hold for transient Magnetars during outburst]



Other accessible persistent magnetars:
SGR 1900+14
rate=19.6480 c/s, 0.74 mCrab, => MDP=3%

SGR 1806-20:
rate=8.4036 c/s, 0.32 mCrab, => MDP=4%

Summary

IXO has the potentiality of largely impacting on our understanding of magnetars (and on isolated neutron stars more in general) under many aspects.

Bursts/Flares:
- QPOs in short bursts and IFs [EOSs] **HTRS**
- polarization of O- and E-mode photons during bursts/flares [trapped fireball] **POL**
- Cyclotron / emission lines during bursts [direct magnetic field measurement] **HTRS**

Outbursts
- variabilita' tra hard e soft X (inizio outburst) - [emission theories] **HXT+(CAL and/or HTRS)**
- flux decay monitoring [emission theories] **HXT - CAL/HTRS**

Quiescence
- Search for new magnetars : faint and in other Galaxies [demography] **HTRS**
- Search for faint X-ray bursts in magnetars/related obj. [demography] **HTRS**
- Polarization as a function of pulse phase [O/E-mode photons] **POL**